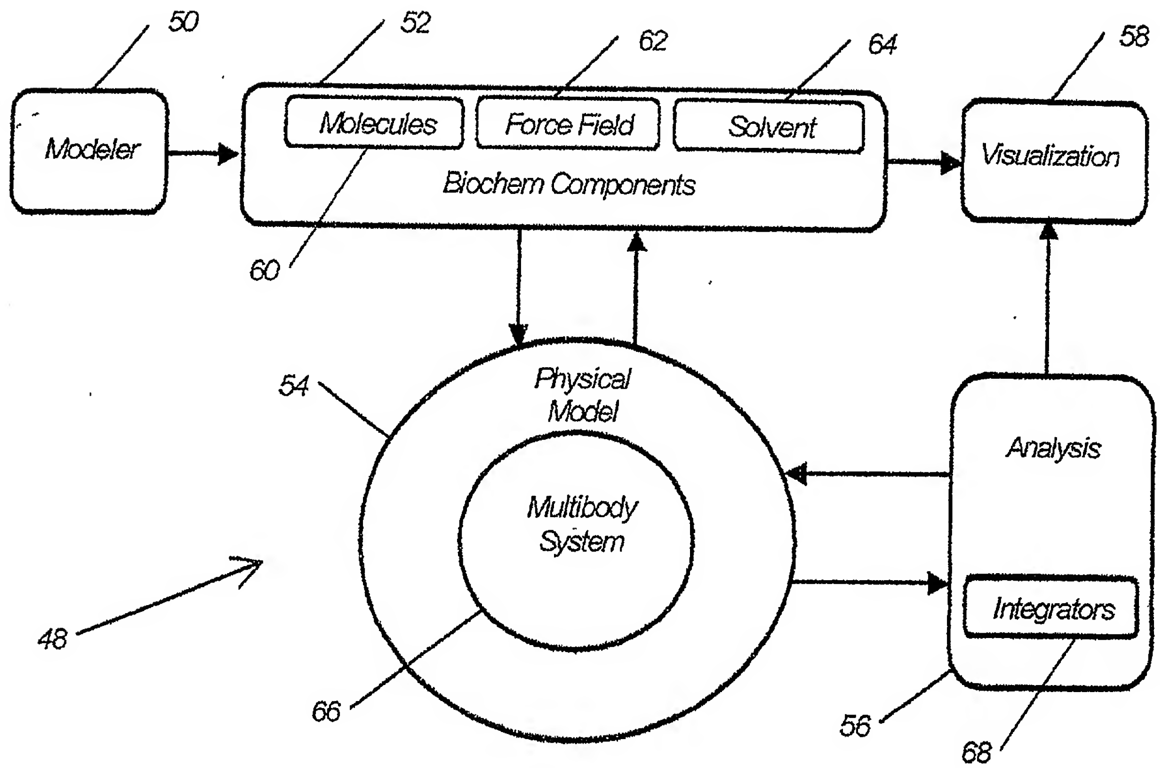
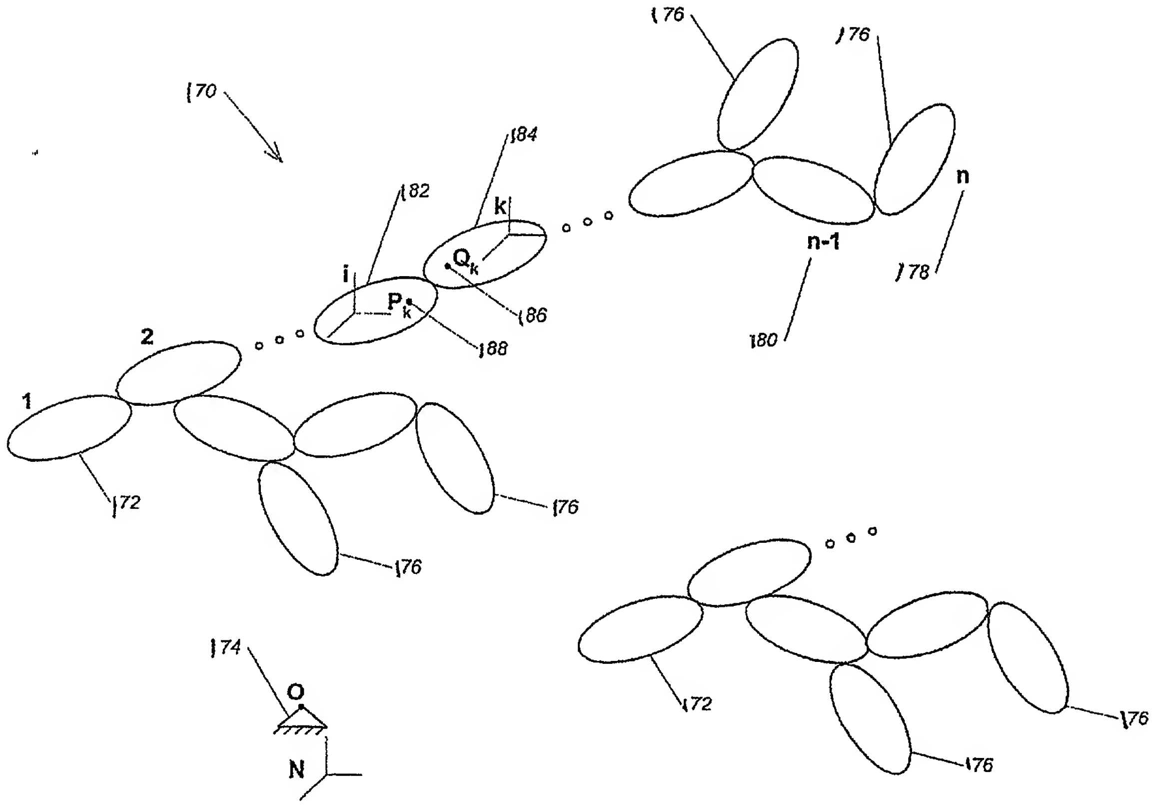


Fig. 1

Residual Form Method to compute ρ_q and ρ_u	Direct Form Method to compute $\dot{q}$ and $\dot{u}$
1. Compute the First Kinematics Calc. and the kinematic residual $\rho_q(k)$ 2. Generate $\hat{T}(k)$, the spatial load balance for each body 3. Compute dynamic residual $\rho_u(k)$	1. Compute $\dot{q}$ using joint specific routines 2. Perform First Kinematics Calc. with $\dot{u}=0$ 3. Generate residuals ρ_u and negate $\rho_u = -\rho_u$ 4. Perform Second Kinematics Calc. 5. Compute $\dot{u}$ using Forward Dynamics

Comparison of Methods

Fig. 5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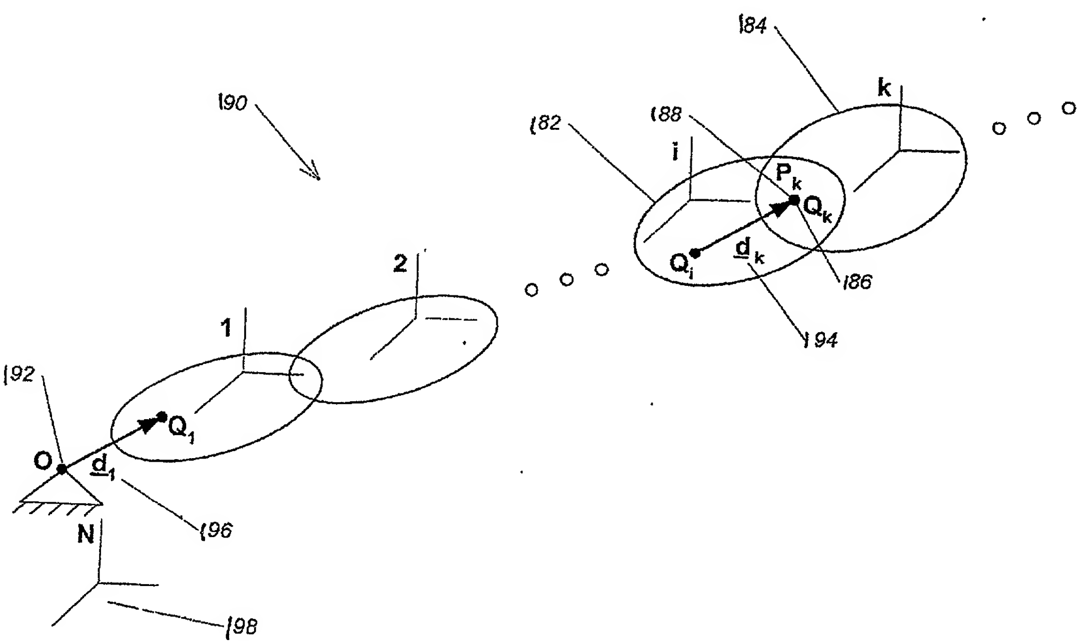
176
176
184
182
k
Qk
n
n-1
i
Pk
186
188
178
180
2
1
172
176
176
174
O
N
172
176
176

Fig. 2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190
188
182
k
i
Pk
Qk
Qi
dk
186
194
2
1
192
Q1
O
d1
196
N
198

Fig. 3

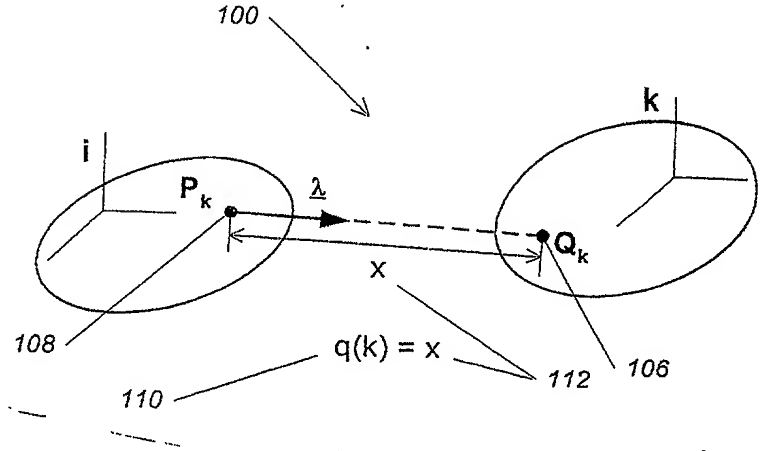

Fig. 4A

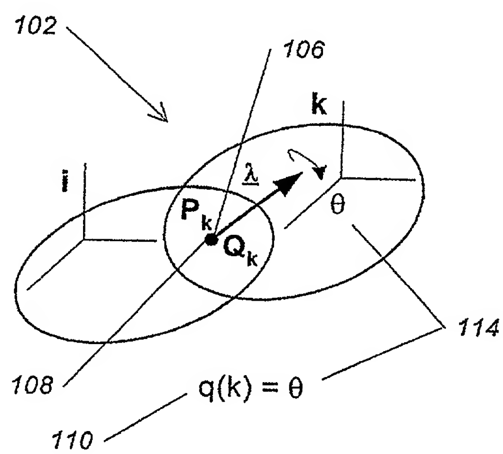

Fig. 4B

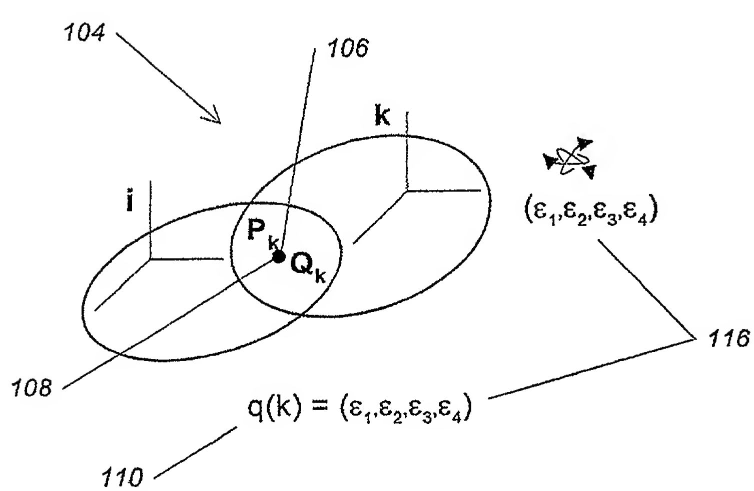

Fig. 4C

Analytic Jacobian Method

1. Compute the analytic Jacobians of the kinematics routines:

$$J_{qq} = \frac{\partial (Wu)}{\partial q} \quad \text{and} \quad J_{qu} = W$$

2. Compute $z \triangleq -M^{-1}\rho_u(q,u,0)$ using the Direct Method

3. Compute the analytic Jacobians of the dynamics Residual routine:

$$\frac{\partial}{\partial q}\rho_u(q,u,z) \quad \text{and} \quad \frac{\partial}{\partial u}\rho_u(q,u,z)\,.$$

4. Backsolve for the analytic Jacobian of the dynamics routine using results for z from the Second Kinematics step:

$$J_{uq} = \frac{\partial \dot{u}}{\partial q} = -M^{-1}\frac{\partial \rho_u(q,u,z)}{\partial q} \quad \text{and}$$

$$J_{uu} = \frac{\partial \dot{u}}{\partial u} = -M^{-1}\frac{\partial \rho_u(q,u,z)}{\partial u}$$

Fig. 6

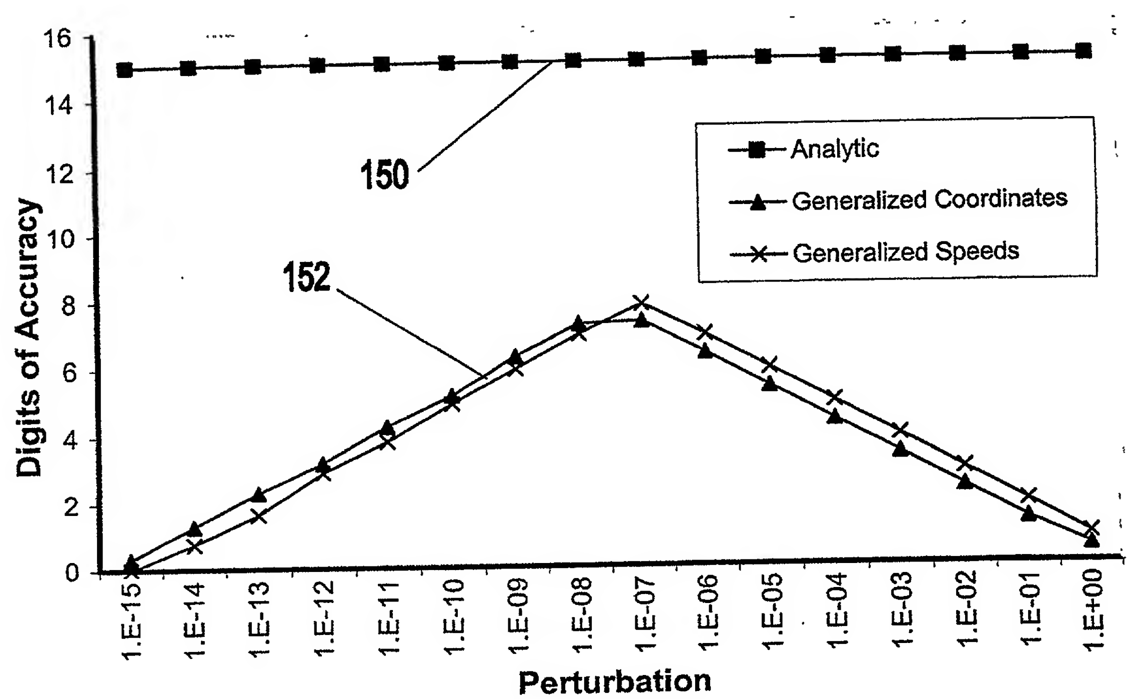

Fig. 7